Regarding the Perceptual Significance and Characterization of Broadband Components of Helicopter Source Noise

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Broadband Components

You've just heard Sidd talking about the tonal components of helicopter noise. This presentation will look at the broadband components.

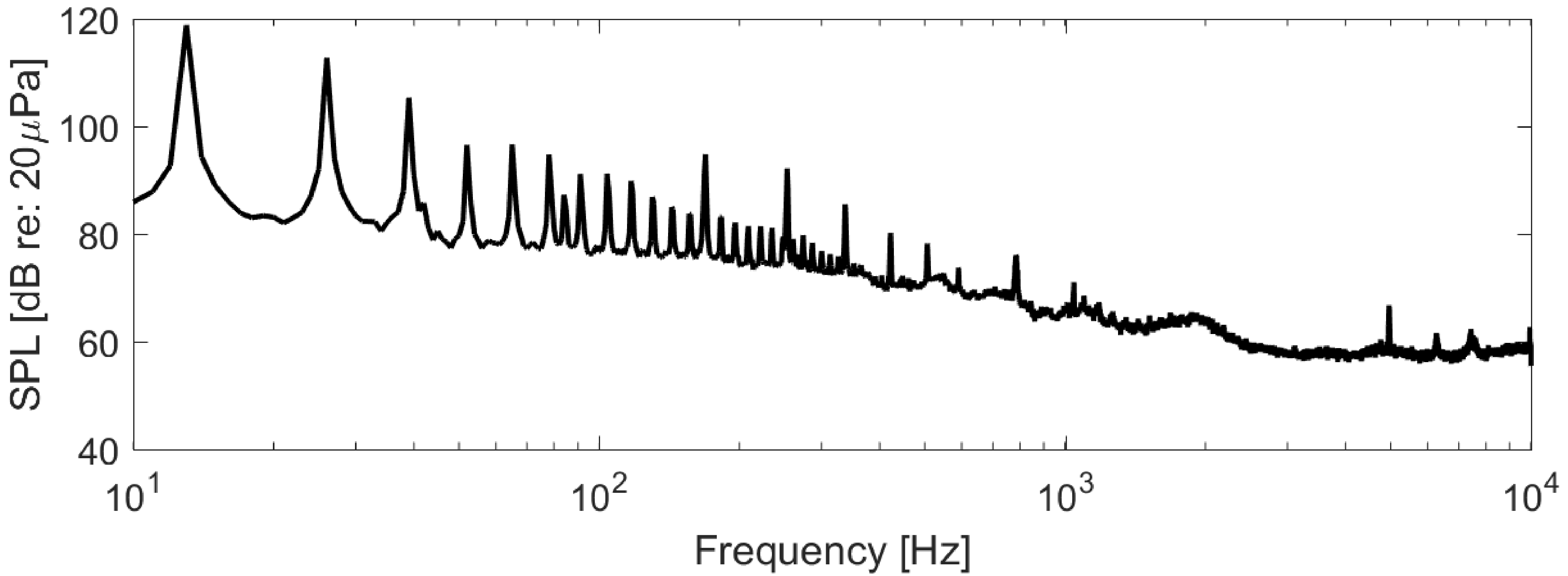
- If these prove to be significant, they may merit a new way of looking at the data.
- This is apart from work on tonal sources – if both are important, both will need to be treated.

A Recording

- Consider a recording of a Bell 206B in straight-and-level flight.
  – The helicopter has been outfitted with microphones on a crop-dusting rig.

[Sound 1]

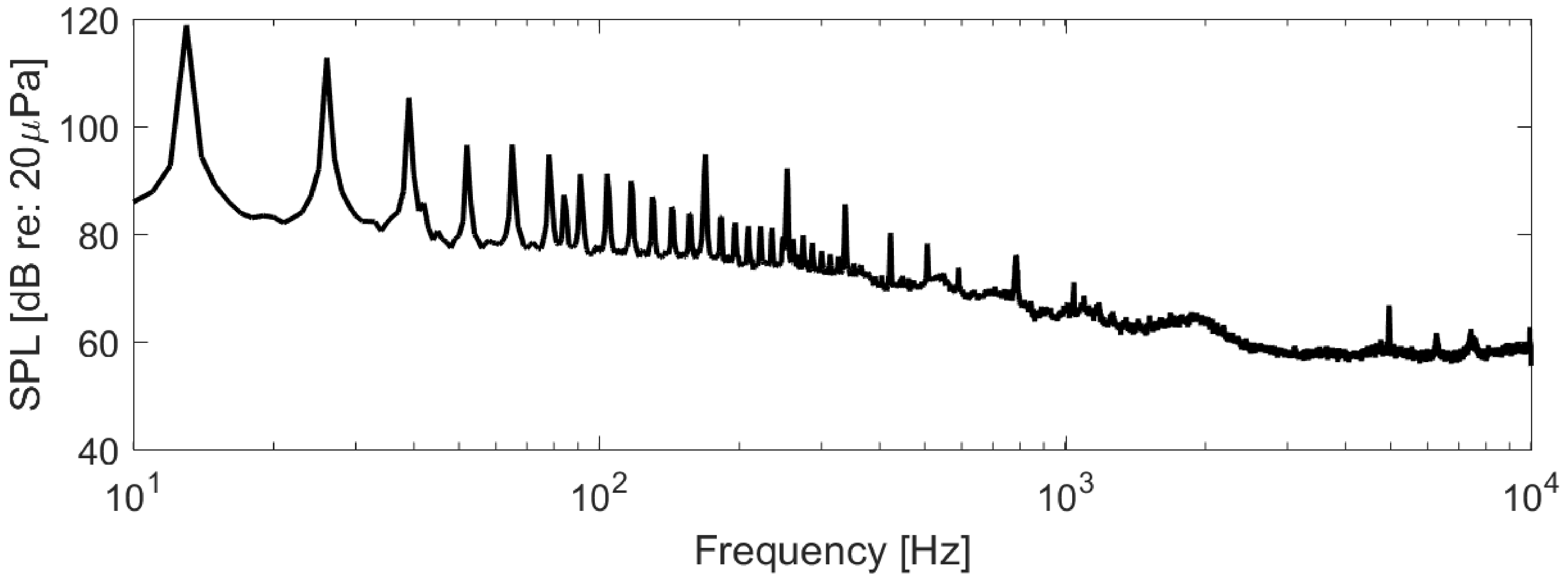
A Recording, Spectrally



- Now consider the power spectrum. (116 averages, $\Delta f = 1$ Hz)
- It has typical helicopter characteristics…

[1]

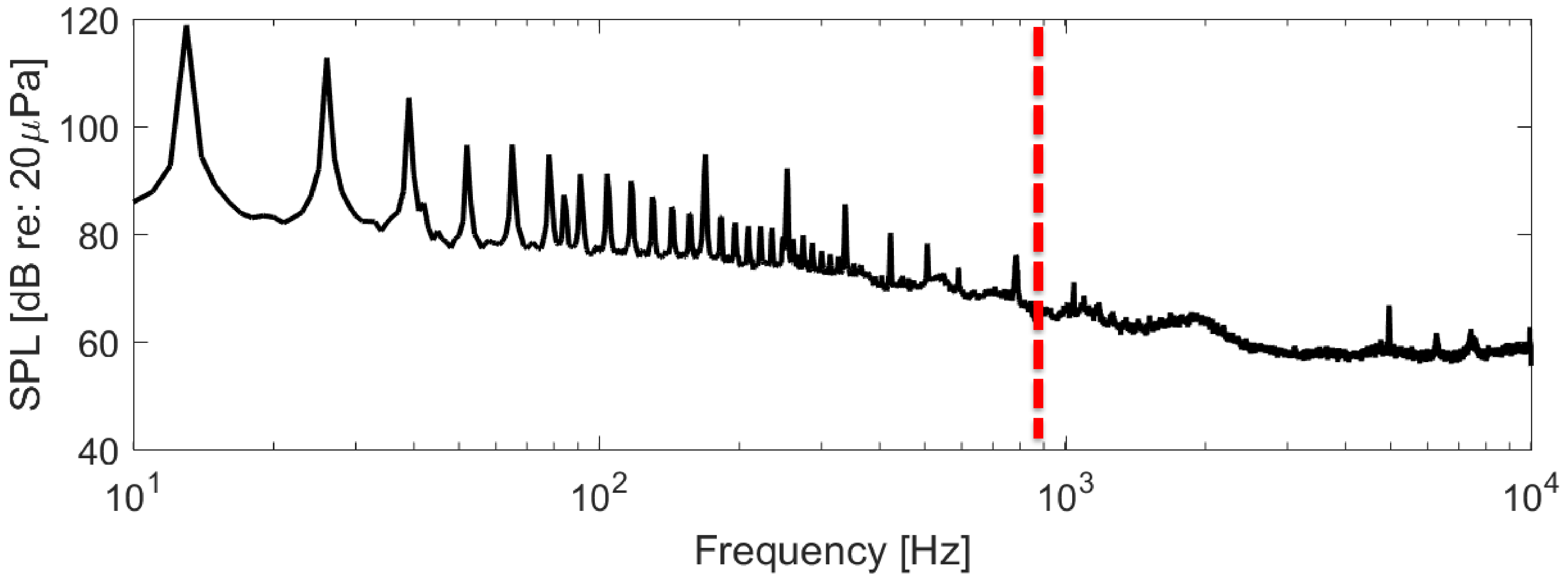
A Recording, Filtered



- Now listen to the recording high-passed (without frequencies below some point).
- Who thinks that the high-frequency portion is still reasonably identifiable as a helicopter?

[2]

A Recording, Filtered

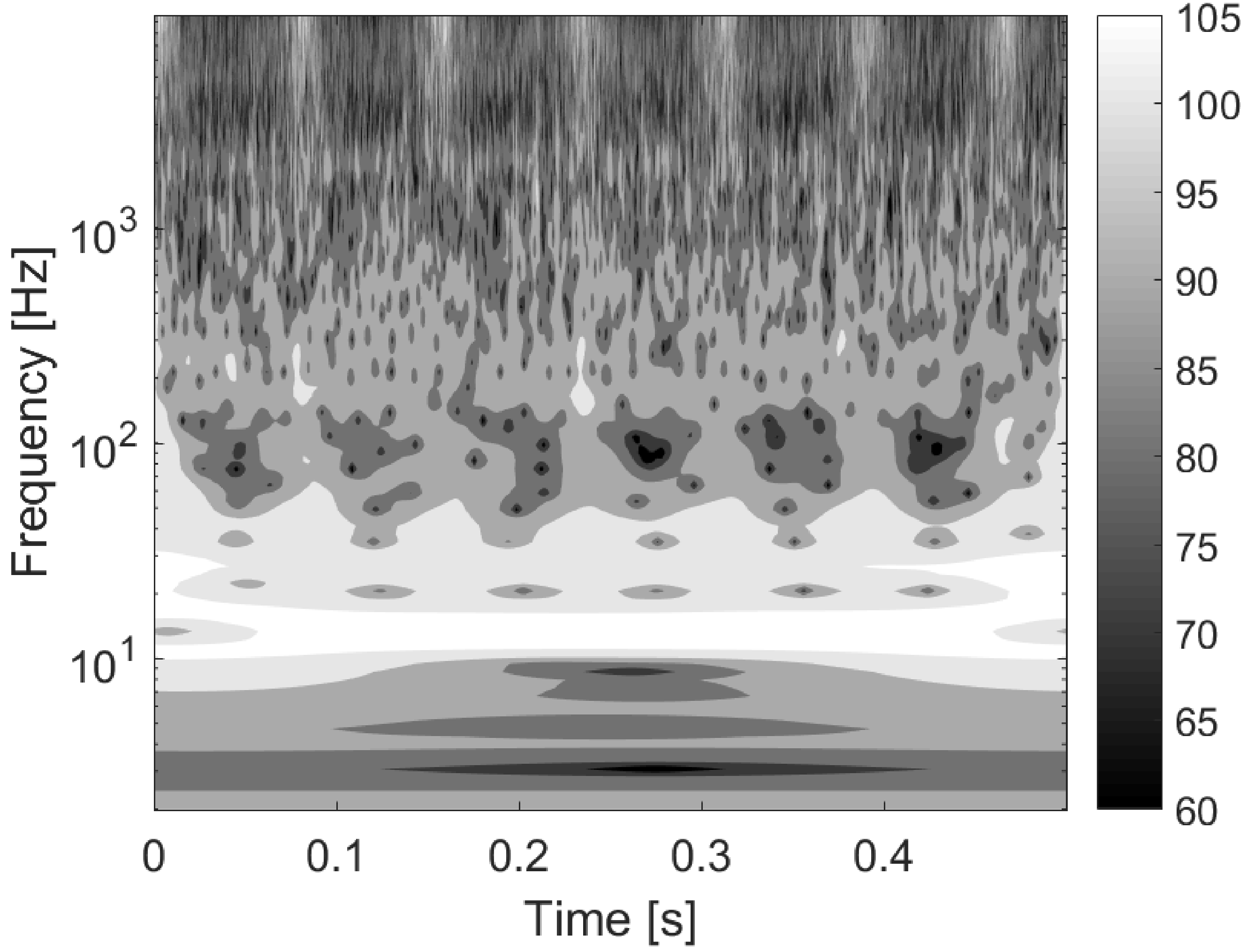


- The partition is around 900 Hz:
  - There are no visible main or tail rotor harmonics above this frequency!
- The A-weighted SPL is the same above and below the partition!

A Recording, In Wavelets

- Consider the wavelet energy spectrum of the recording:
  - The high frequencies are *not* constant broadband noise.
  - There is a series of pulses at the blade-passing frequency.

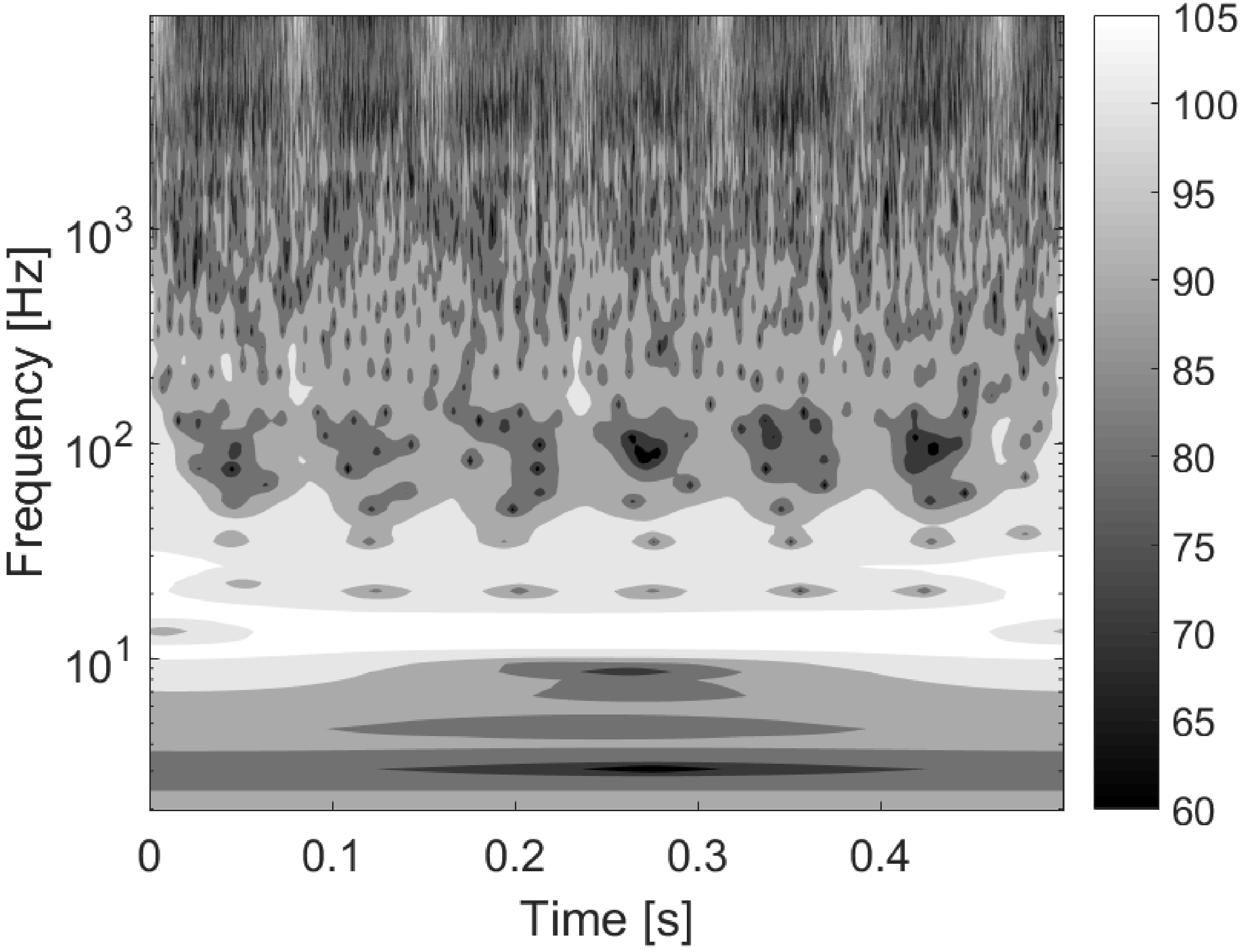
[2]



Why Is This A Problem?

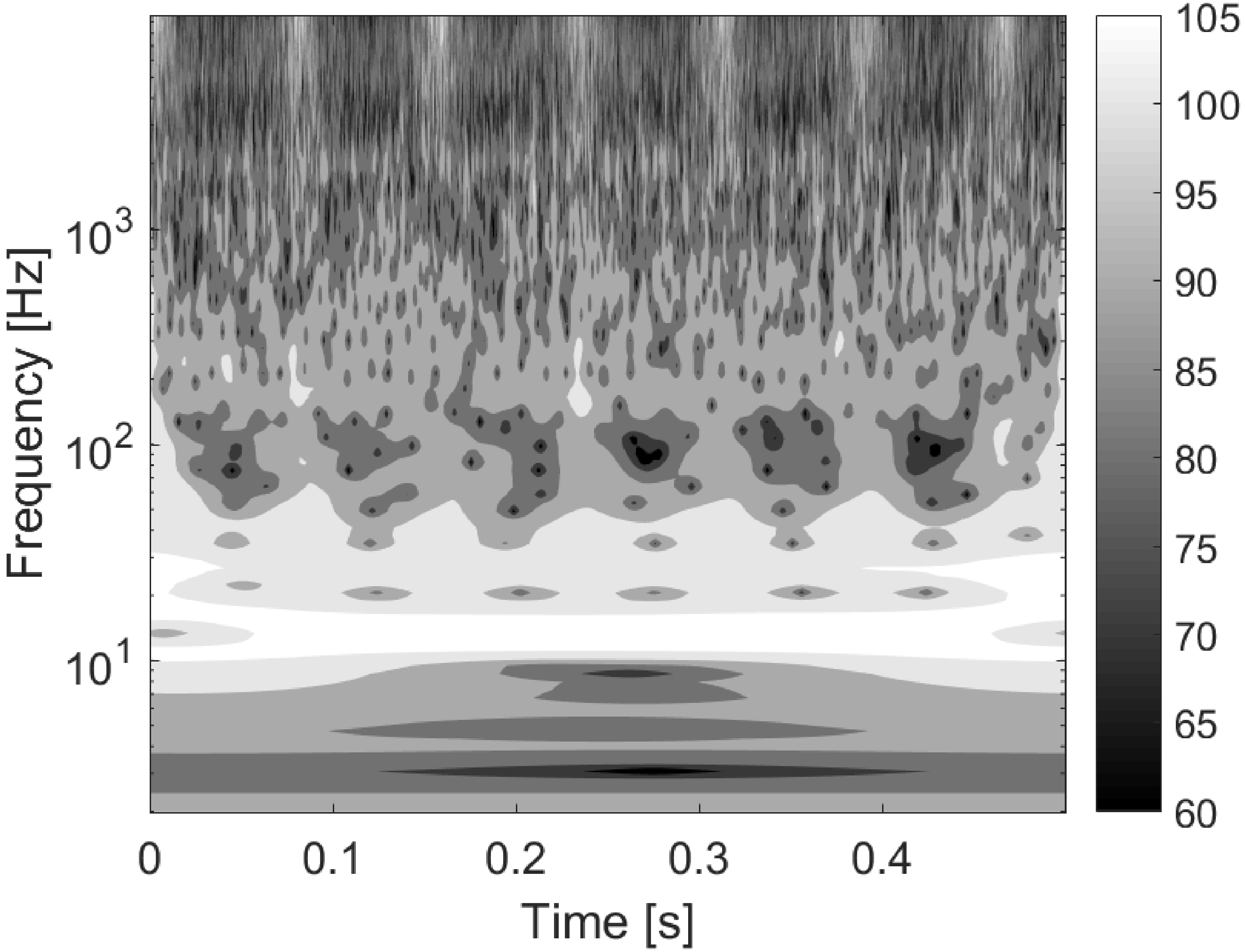
- No contemporary method for analysis of helicopter noise is formulated to treat broadband noise for which the *structure* is a salient feature.

- This feature conveys just as much information on the identity of the sound, and is just as loud as the rest of the signature!
  – Very close to the source…



Why Is This A Problem?

- The balance between tonal and broadband content is expected to swing toward the latter for:
  - Lower tip speeds
  - Closer proximity of observers



What Does This Mean?

Having considered the high-frequency noise of this recording, what are the implications in terms of sound quality?

- Auditory sensations like roughness
- Unsteadiness

Sound Quality Implications

Modulated high-frequency noise is known to generate the sensations of Roughness, Fluctuation and possibly Impulsiveness:

- Fluctuation – Active between .1 and 30 Hz, peaking near 4 Hz
- Roughness – Active between 15 and 300 Hz, peaking near 70 Hz
- Impulsiveness – Related to the 'duty cycle' of the modulation

White Noise [3]

[5] Rough

Fluctuating [4]

[6] Impulsive

Sound Quality Implications

Modulated high-frequency noise is known to generate the sensations of Roughness and Modulation and possibly Impulsiveness:

- The noise seen here may impact all 3 of these. [7]
  - White noise modulated impulsively at 20 Hz:

All of these sensations have been previously correlated with increased annoyance, though particular correlations seem to be vehicle/situation dependent.

A Mechanism for Unsteadiness

Short noise pulses have a tendency to create a sense of unsteadiness due to their statistical uncertainty.

- Wide-band and long pulses seem rather constant: [8]
  - White noise, 5 kHz wide, 200 ms bursts. (BT = 1000)
- Reducing the length of the bursts produces unsteadiness: [9]
  - The observed pulses are about 5 kHz wide, but only 10 ms long. (BT = 50)

Characterization and Resynthesis

The observed high-frequency broadband pulses are liable to create all of these effects:

- Fluctuation
- Roughness
- Impulsiveness
- Unsteadiness

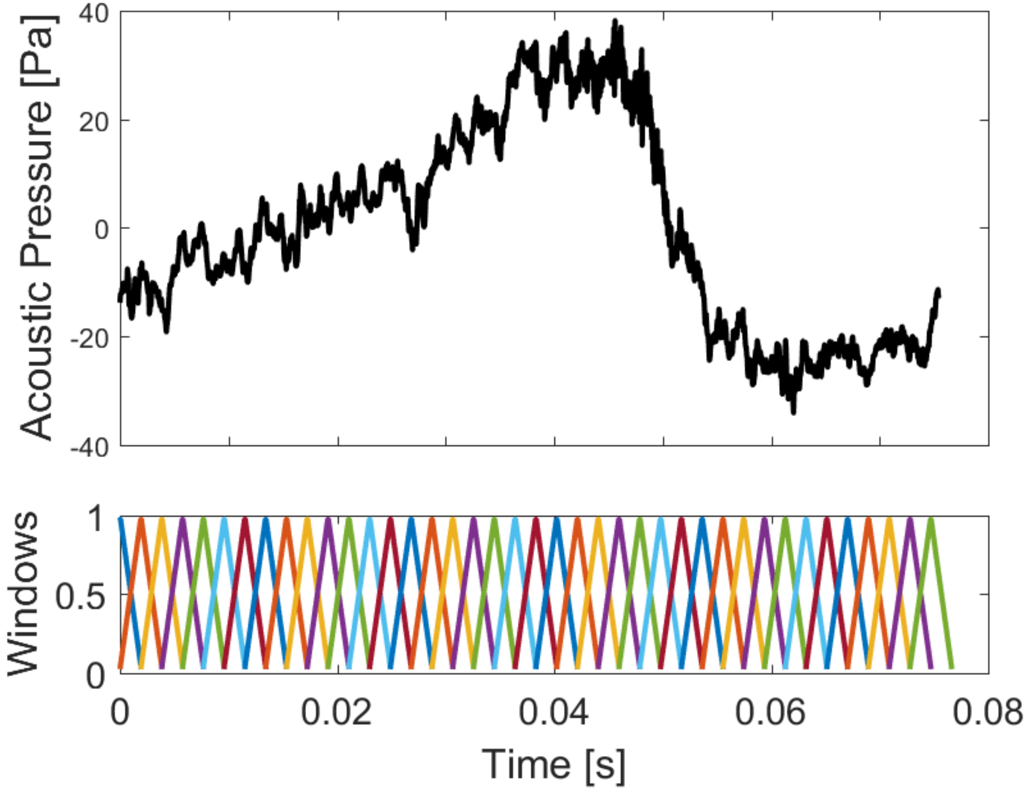
But the demonstrations so far have all been with contrived sounds. Will the pulses actually observed in the signal act in these ways?

→ The pulses need to characterized and resynthesized.

Characterization

Generally, the approach shown augments that of Greenwood and Schmitz:

1. **Break the signal into individual blade passage records.**
2. **Take many short discrete Fourier transforms per-blade passage.**
3. Turn these DFTs into power spectra.
4. Aggregate the spectral bins into one-third octave bands.
5. Average over the blade passages.



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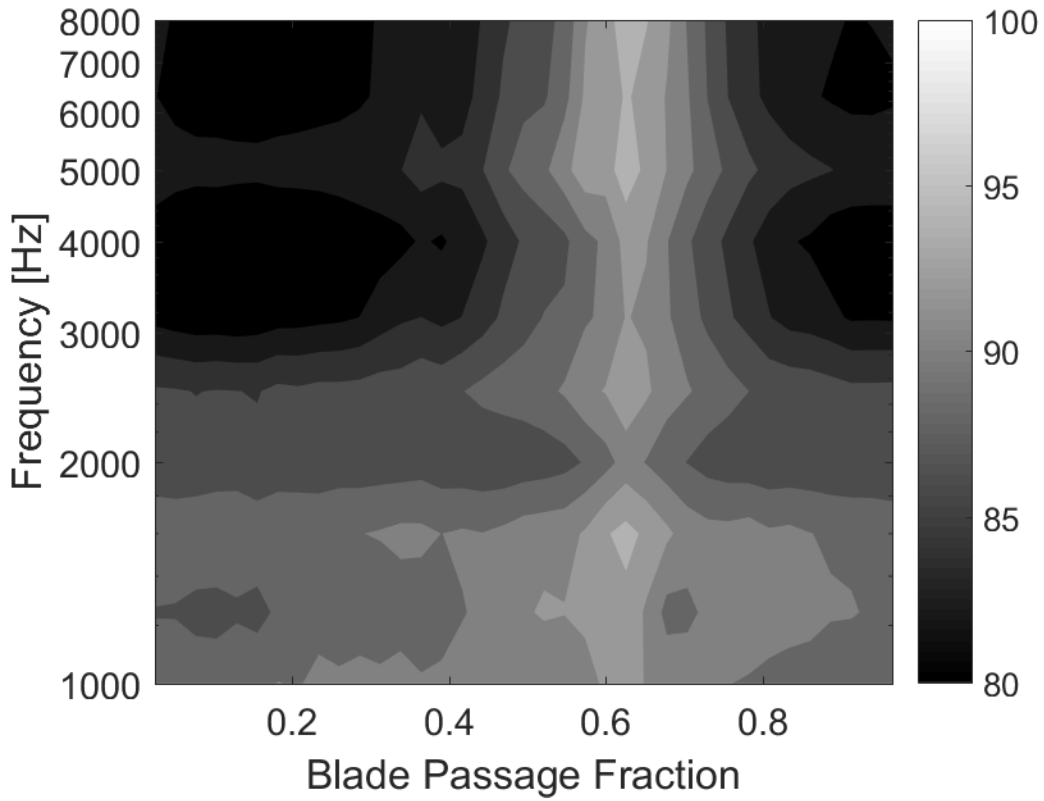
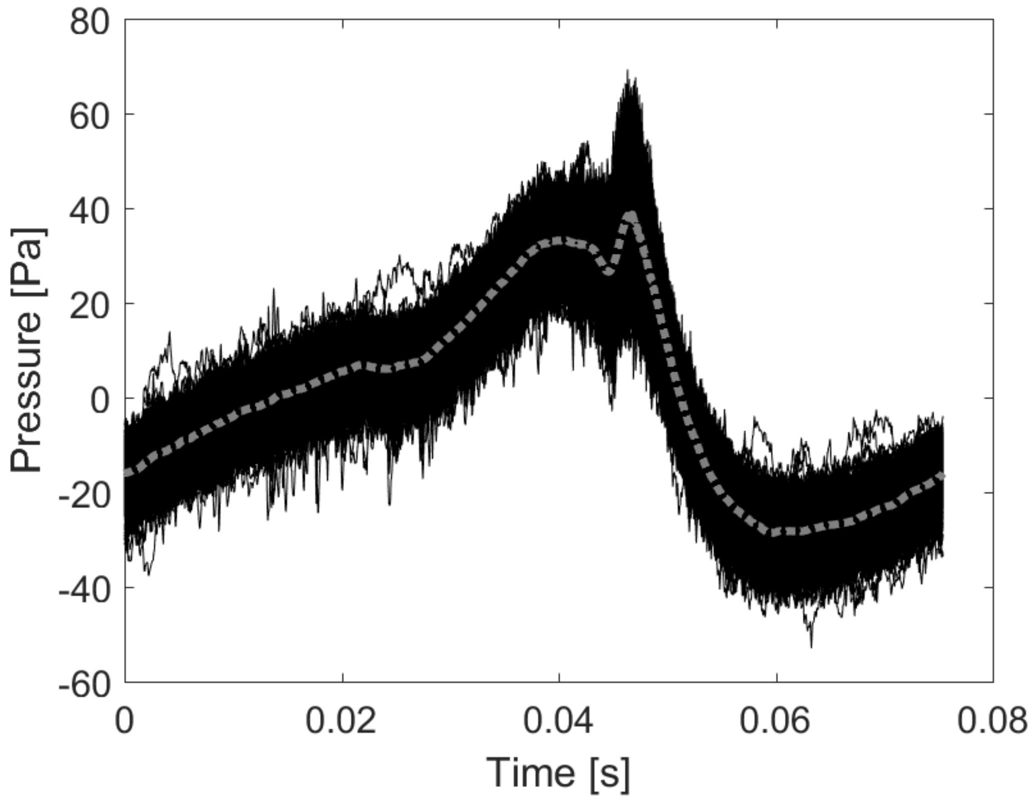


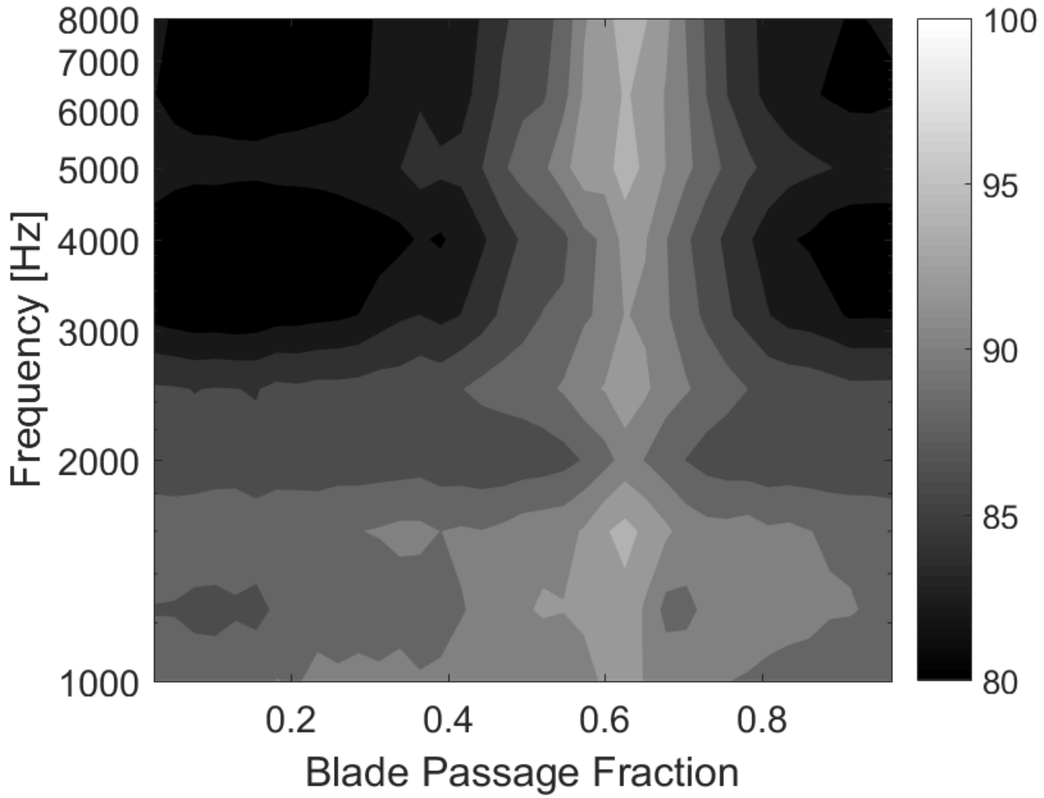
Characterization

There is a lot of room for improvement of this method, so it's not important to go into too many details. The most significant points:

- This method generates one-third octave band data, which is akin to the output of aeroacoustic prediction codes.
  - As opposed to a wavelet-based method, for example.
- This method uses DFTs that are smaller than a blade passage.
  - Most methods for characterizing helicopter noise work on the signal only on a scale small enough to resolve the main rotor blade-passage frequency, but this destroys information that happens on a time scale smaller than this.

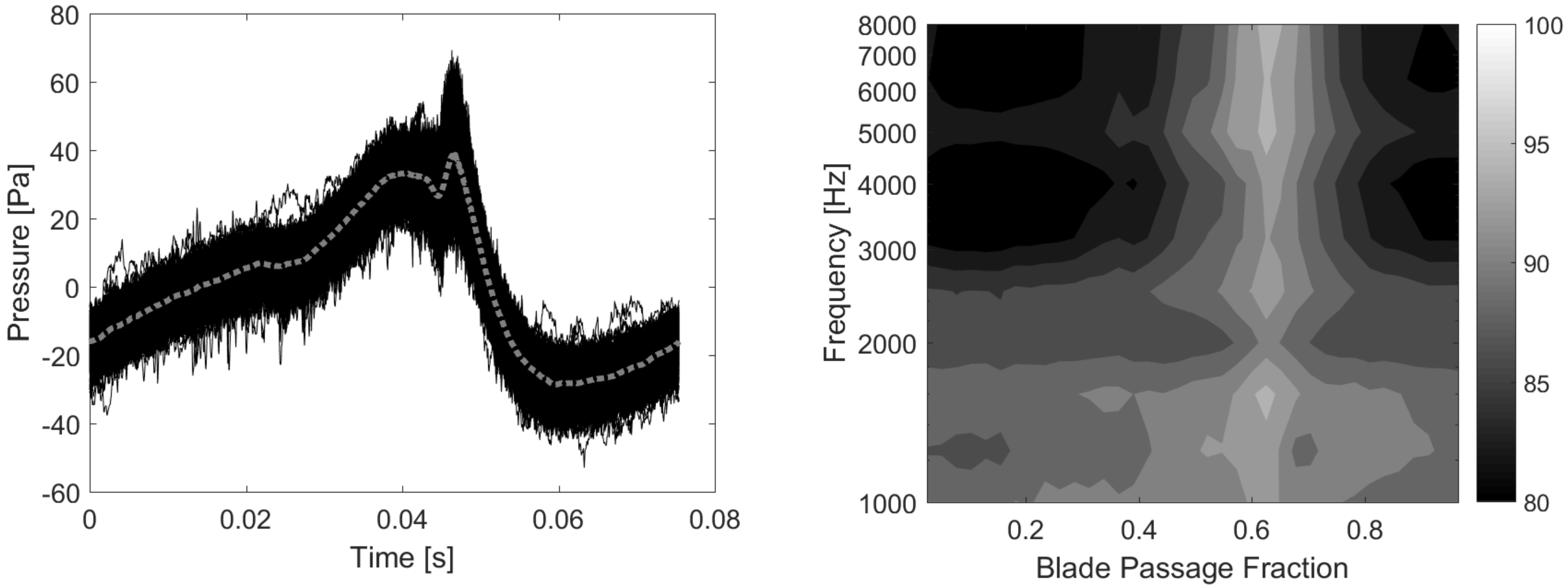
Characterization of the Bell 206B





- Time-averaged main and tail rotor pulses.
- Time-frequency average modulation of HF noise. (Pink LF noise.)

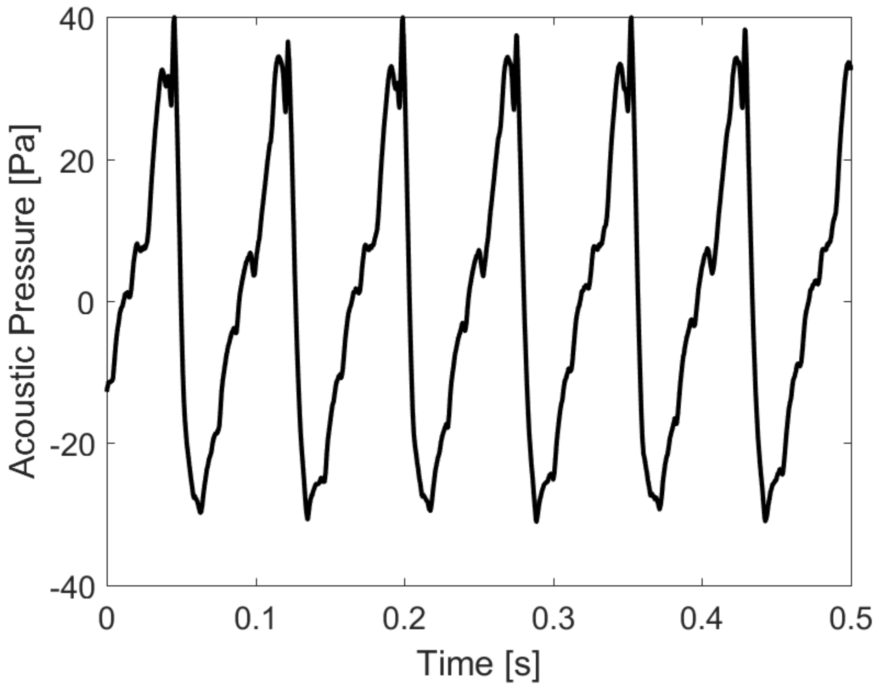
Characterization of the Bell 206B



N.B. The plot on the right *cannot* be produced from the grey line on the left – time averaging destroys broadband information!

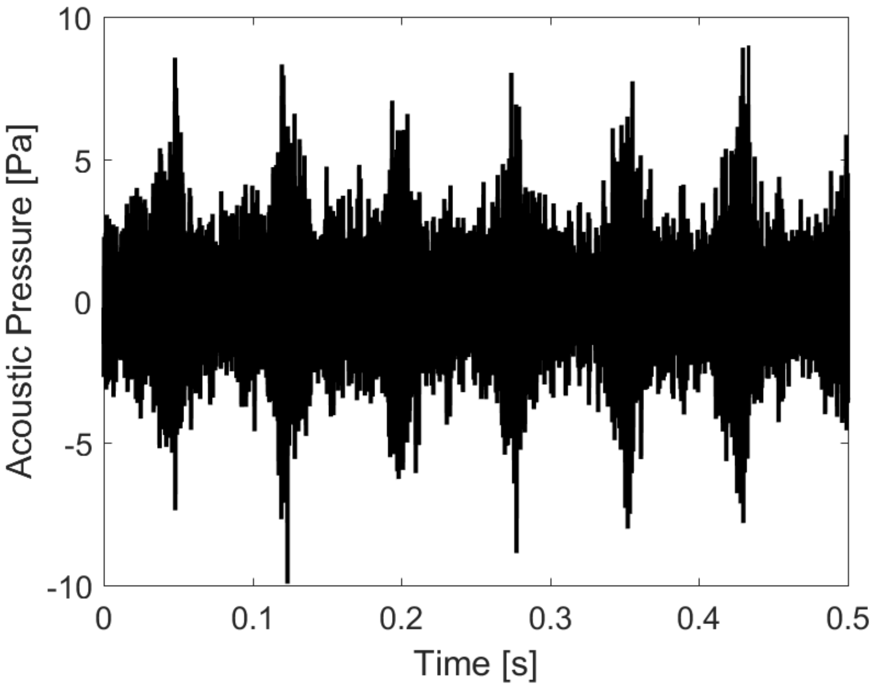
Resynthesis

Main and Tail Rotors (Deterministic)



[10]

Modulating Noise (Stochastic)

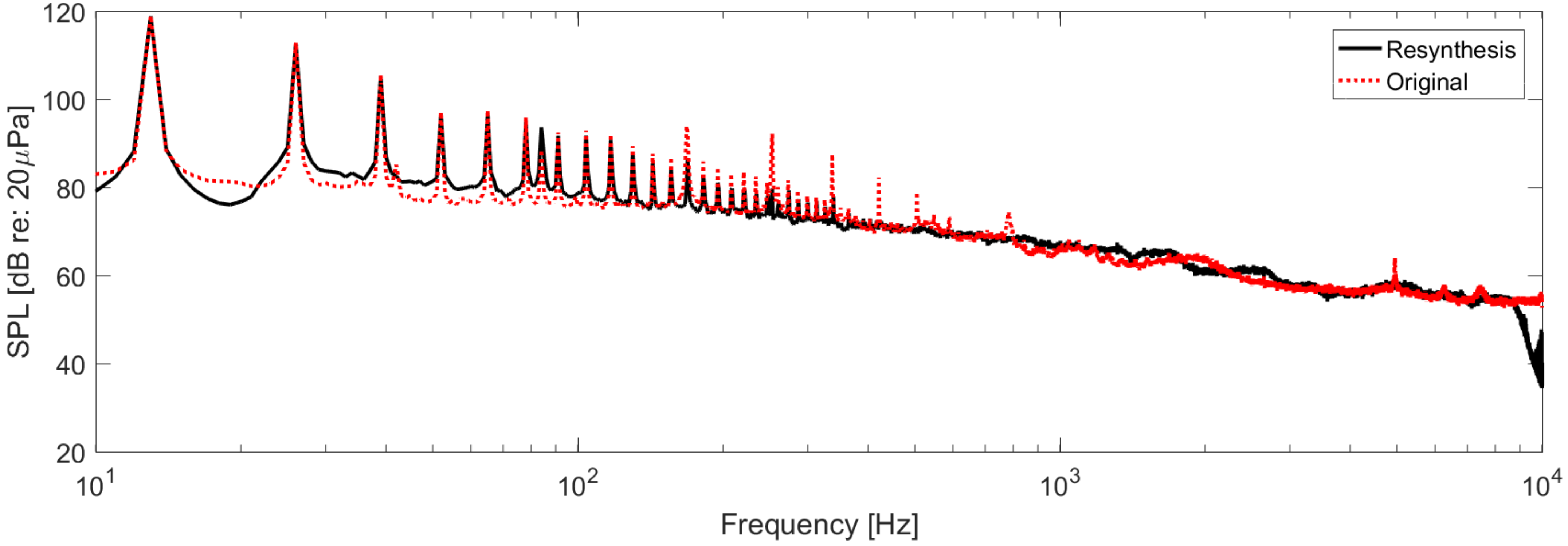


[11]

Total Resynthesis

Original [1]

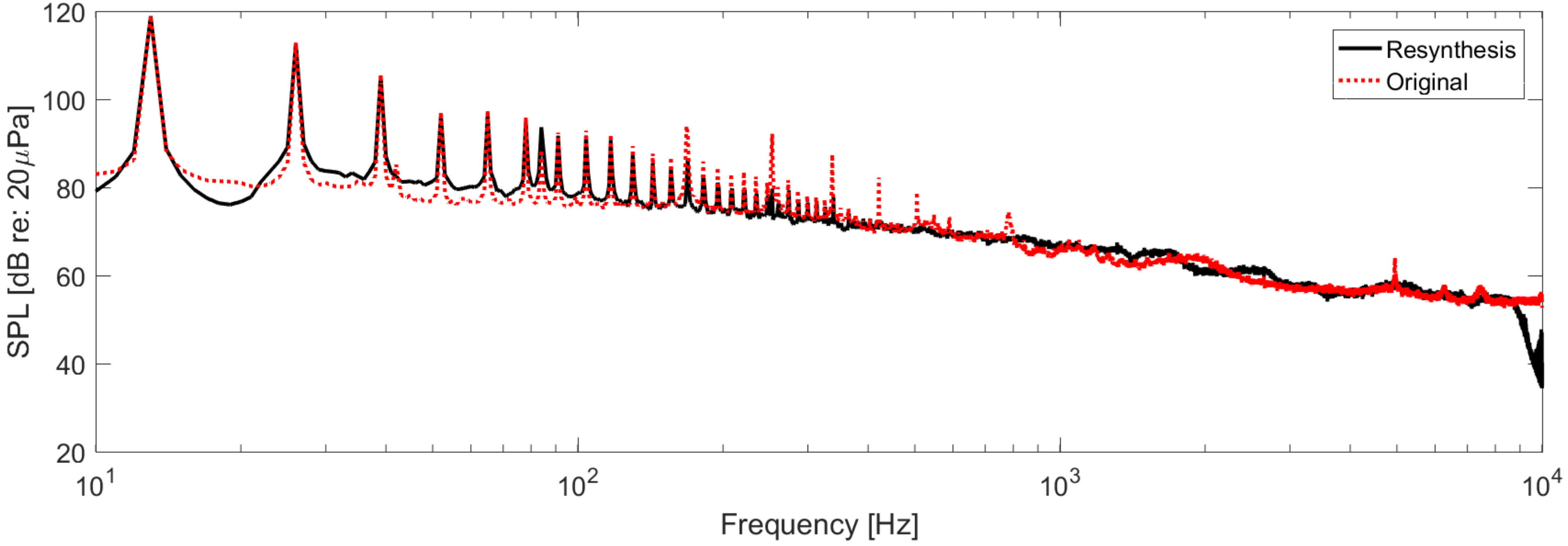
[12] Resynthesis



Total Resynthesis

Filtered Recording [2]

[11] Modulated Noise



The Comparison

Features that are lacking/destroyed:

- Perfect agreement in frequency content
- Long-term unsteadiness
- Engine/transmission tones
- Energy from the tail rotor harmonics
- High-frequency 'definition'

Features that are recreated:

- Good agreement with the overall noise level
- Short-term unsteadiness
- (Likely) Sound qualities such as roughness are well-preserved

Outlook and Future Work

- So far this work has been completed through intern effort. This trend will continue this summer with work to:
  - Extend predictions of this noise to allow the creation of flyovers
  - Integration of this method with other approaches (e.g., Krishnamurthy)
  - Comparisons of the source noise with ground data of the Bell 206B
- Given the significance of the results, it may find its way into future mainline plans:
  - General research into rotorcraft unsteadiness and auralization
  - Psychoacoustic tests (e.g., of auralization fidelity)

Note the AHS Paper

- This work is scheduled to be released and presented at the upcoming Vertical Flight Society Forum.

- Including:
  - Gory signal processing details
  - Pontification on the source mechanisms
  - Auralizations entirely from predictions

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ABSTRACT

This paper that attempts to characterize the high-frequency components of in-flight near-field noise measurements of a Bell 206B helicopter. This noise is shown to be largely broadband, in which case, many existing characterization methods are not expected to produce meaningful results. The development of a frequency domain technique is given which uses very short (in time) discrete Fourier transforms with windowing and overlap in order to produce a representation of how the 1/3rd octave band spectrum of the noise varies over time scales shorter than a blade passage. The output of this method can be used to resynthesize the source noise. This resynthesis evidences natural variations that are perceptually similar to those seen in the original recording, and which would not be predicted by contemporary rotorcraft noise analysis techniques. The implications of the significance of this noise component on future prediction and auralization efforts is discussed. ERIC ADD MORE?

INTRODUCTION

Helicopter noise, and the annoyance therefrom, remains a thorn in the side of regulators and researchers. It appears in some instances to generate an inordinate amount of community response, while in others it appears to be rather benign (see, for instance, the recent ACRP review and report (Ref. 1)). What is generally agreed upon is that it is, overall, a more complex phenomenon than many other common sources of noise (ibid.).

In an effort to unwind this complexity, it is desirable to be able to "dissect" noise that was recorded from helicopters either in flight, (Ref. 3) or from ground-based microphones (Ref. 4). Recently, a number of approaches for doing this have been proposed: Greenwood (Ref. 5) uses a wavelet method to facilitate time-averaging of the rotor pulses. Krishnamurthy et al. (Refs. 6, 7) uses a Fourier approach that employs a set of energy-conserving bandpass filters to partition the noise into stationary and time-varying components. Olsman (Ref. 8) used a similar approach to Krishnamurthy, though employing a spline interpolation technique to characterize the time-variation of the pulses. The fraction of the noise treated by these methods can be referred to as the "tonal" component, as it is made up of sinusoidal harmonics, with definite phase relationships, beginning from the main and tail rotor blade passage frequencies (BPFs). This tonal noise seems to be tacitly regarded as the most perceptually significant component in many settings (e.g., detection (Ref. 9)). It is also the most tractable via contemporary aeroacoustic analyses using acoustic analogy methods (Refs. 10, 11).

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The objective of this paper presents initial steps toward better understanding of the role of broadband sources in helicopter noise. If broadband components are significant,[1] they will not be properly analyzed by any of the aforementioned decomposition methods. That is, even if a method is conservative — the original recorded signal can be regenerated from the partitioned data — the concept of what is an average and time varying component will not be meaningfully applied to a component of noise that is broadband.

The paper begins by presenting recordings of the near-field noise of a helicopter, and discussing the implications of basic observations that are made from basic analyses (low- and high-pass filtering). It then presents some rudiments of psychoacoustics and signal processing which give impetus to the analysis method that is detailed in the following section. After that, the analysis method is demonstrated on the same near-field data, and a resynthesis is produced.

THINGS FROM ERIC?

Throughout this paper, attributes of sounds are discussed which are not clearly evident from the plots shown (time series, and power and wavelet spectra). Readers are encouraged to "listen along" to these sounds, which are available on the NASA Structural Acoustics Branch website:

https://stabserv.larc.nasa.gov/flyover/

A summary of these sounds is given in Appendix A.

IMPETUS AND CONCEPTS

This research stems largely from the observation that, given a recording of helicopter source noise, it is possible to filter out

[1]See, for instance, recent results by Zawodny indicating that broadband components might constitute the majority of sources for a small UAV from an A-weighted point of view (Ref. 12).

1

Acknowledgements

- This work has simmered for a long time in the minds of the authors. People who deserve credit for adding thoughts to the soup at crucial moments include:

  Ben Sim, Siddhartha Krishnamurthy, James Stephenson, Nik Zawodny, Steve Rizzi, Menachem Rafaelof, Kevin Shepherd, and likely many others.

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Questions

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